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RESPONSE OF THE KNAPWEED BIOCONTROL AGENT *AGAPETA ZOEGANA* L. (LEPIDOPTERA: COCHYLIDAE) TO PORTABLE LIGHTS

J. M. STORY, W. R. GOOD, & L. J. WHITE
Western Agricultural Research Center,
Montana Agricultural Experiment Station, Corvallis, Montana 59828

Abstract.—*Agapeta zoegana* L. is a Eurasian root-mining moth introduced into North America for biological control of spotted knapweed, *Centaurea maculosa* Lamarck. The moth is established but is difficult to collect for redistribution. A study was conducted during July and August 1997 and 1998 to assess the noctural response of the moth to portable fluorescent and ultraviolet lights, and to determine if portable lights would aid in the collection of *A. zoegana* adults. The moth's attraction to portable lights was assessed during four 20-minute illumination periods beginning at 50, 95, 140, and 185 minutes after sunset (MAS). The mean number of male *A. zoegana* attracted to the portable lights was significantly higher than females during the 95 MAS (sex ratio 95:5) and 140 MAS (80:20), but was not different from females at the 50 MAS and 185 MAS periods. Male numbers were especially high at the 95 MAS period when an average of 113 males were sampled. Female numbers were very low at all four illumination periods, averaging around four individuals per period. Male and female numbers during daytime hours were not significantly different which indicated the disproportionately high number of males attracted to the portable lights was related to moth behavior rather than population sex ratio. Fluorescent and ultraviolet light were equally attractive to the moth. The use of portable lights in the field is an effective method for determining establishment of *A. zoegana,* but is not recommended for collection of moths for redistribution to new sites because of the low proportion of females collected during the illumination periods studied.

Key Words.—Insecta, *Agapeta zoegana,* portable light, spotted knapweed, collection.

Agapeta zoegana L. (Lepidoptera: Cochylidae), is a Eurasian root-mining moth introduced into North America for biological control of spotted knapweed, *Centaurea maculosa* Lamarck (Asteraceae). The first U.S. release of the moth was made in Montana in 1984. The biology, host specificity, and potential impact of the moth were described by Müller et al. (1988), Müller (1989) and Story et al. (2000). The moth overwinters as a larva in the knapweed root and emerges as an adult between mid-June and mid-September, with peak emergence occurring in early August (Story et al. 1991). Females begin mating on the day of emergence and usually begin ovipositing on the second night. The sex ratio of adults is 1:1 throughout most of the season (Story et al. 1991). The moth apparently has only one generation per year in Montana.

The moth is now well established at a number of sites in Montana. Collection of *A. zoegana* larvae is very difficult so methods to collect the adults at these sites for distribution to other locations are being assessed. Because *A. zoegana* adults have shown some attraction to lights (Fitzpatrick 1989), and the attraction of moths, in general, to lights is well documented, the possible use of portable lights to aid in field collection of the moth was of interest (Southwood 1978, Tucker 1983, Sorensen & Thompson 1984, Simmons & Elliott 1985, Taylor 1986, Gregg et al. 1993). The objectives of the study were to determine if time of night and type of light source influence the attraction of adult *A. zoegana* to portable lights, and whether these lights will aid in moth collections.

Materials and Methods

Study location.—The study was conducted on the Teller Wildlife Refuge near Corvallis, Montana, USA (46°19′ N latitude, 114°09′ W longitude, elevation 1057 m). The study area was an abandoned pasture dominated by spotted knapweed (59% relative abundance), grass species (35%), and miscellaneous forbs (6%). Spotted knapweed was distributed throughout the field. The study area was approximately 0.8 km from the nearest buildings and associated lights.

Study procedure.—The study was conducted from approximately 2100 to 2400 h (MDT) on seven nights in 1997 and six nights in 1998 during late July through August (i.e., the primary period of adult *A. zoegana* emergence). A portable, 18-watt, battery-powered fluorescent light was illuminated for four 20-minute periods per night beginning at 50, 95, 140, and 185 minutes after sunset (MAS), with a 25-minute interval between illumination periods. These illumination periods are hereafter referred to as the 50 MAS, 95 MAS, 140 MAS, and 185 MAS illumination periods. Official sunset times for the area were obtained from The World Almanac (1997, 1998). Each illumination period was conducted at one of four sites located at approximately 110 m intervals along a private road. The four sites had comparable *A. zoegana* populations, as determined by visual counts of the moth made during the pevious afternoon. The order in which sites were sampled was changed each night to eliminate any time-of-night bias between sites. The 25-min interval between illumination periods allowed for the relocation of equipment to the next predetermined site. In 1997, all of the sampling per night was done by a single collector; in 1998, the same procedure was followed except that two collectors worked simultaneously in separate widely-spaced (> 250 m) sets of four collection sites, with one collector using the fluorescent light and the other using a 15-watt ultraviolet light (black light). The light-source types were alternated between the four-site on ensuing sampling nights. Sampling was done on warm, calm nights due to daytime observations which indicated the moths are reluctant to fly under windy conditions. Mean air temperature at 2200 h (MDT) on sampling nights was 19° C.

Equipment consisted of a white linen sheet, the portable light, and a tripod comprised of wooden poles (6 cm diam. and 2.5 m long) secured with a rope. The tripod was erected at a collection site, the sheet was draped over the tripod, and the light was suspended from the tripod approximately 0.8 m above the ground. All *A. zoegana* adults alighting on the illuminated sheet during the illumination period were vacuumed into one-liter paper cans with a modified hand vacuum (Story et al. 1999). Upon completion of the sampling for the night, the containers were held in a refrigerator at 4° C. During the morning following the night collection, the moths were sexed in the laboratory and then released at the collection sites.

The number of sampling nights was limited due to the avoidance of nights that were moonlit during 2100 to 2400 h, and the attempt to minimize impacts on the *A. zoegana* population. Preliminary observations indicated that portable lights were not as effective on moonlit nights.

Daytime collections of the moth were made on an afternoon within 24 hours (before or after) of the night collection. The daytime collections were made on calm days as explained earlier. The moths, which spend the daylight hours cling-

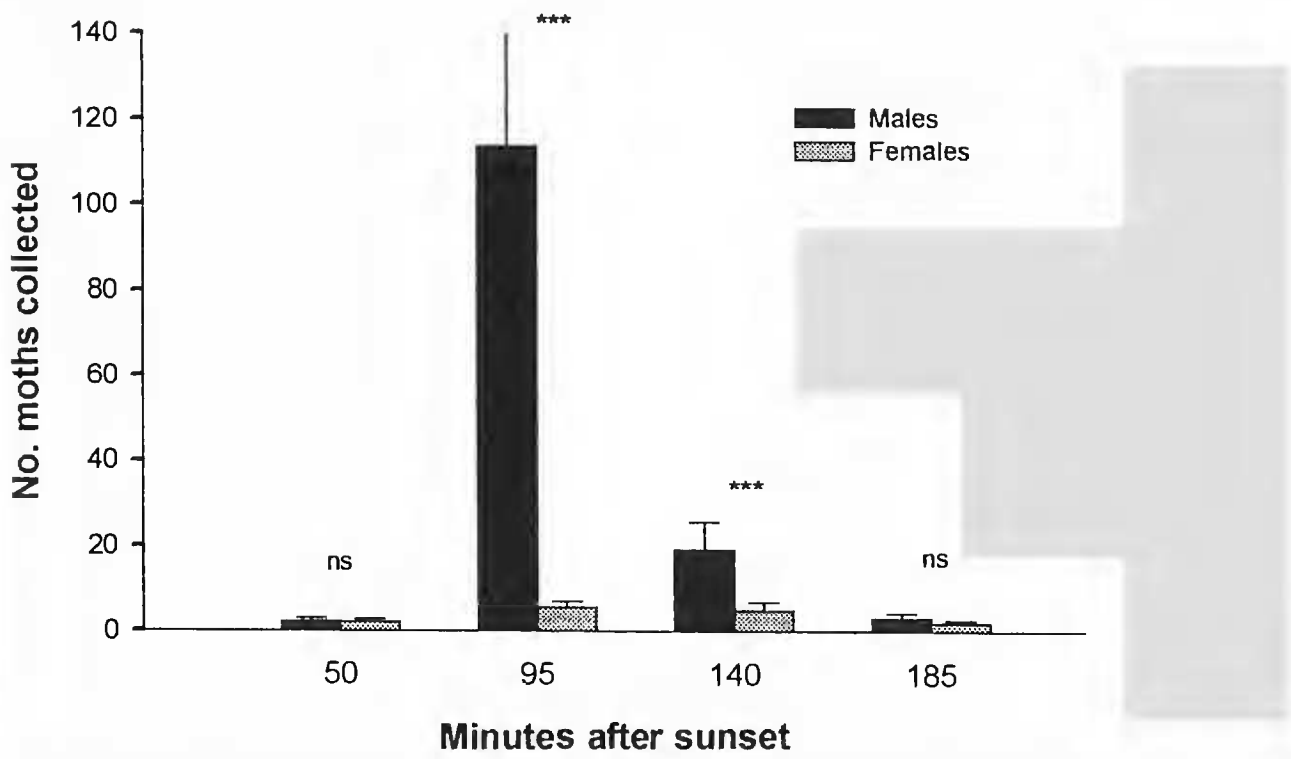

Figure 1. Mean number of *A. zoegana* adults collected at portable lights per illumination period in 1997 and 1998 (mean ± SEM); Student's *t*-test; ns = nonsignificant; *** = $P < 0.001$.

ing to knapweed plants, were collected near (but not at) each of the night collection sites with the use of the modified hand vacuum. Two or three people experienced with the use of hand vacuums collected moths for a total of 20 person-minutes per site. Each person collected every moth seen along individual, circuitous routes through each site. The collected moths were sexed in the laboratory and then released in the collection areas.

Most of the data were analyzed using analysis of variance (ANOVA) using Statistix For Windows (Analytical Software 1996). The Student's *t*-test was used to compare male and female moth numbers at each illumination period, and to compare male and female numbers in portable light versus daytime hand-vacuum collections. Mean comparisons were made with the least significant difference test.

Results

Results of the portable light collections averaged across both 1997 and 1998 are shown in Fig. 1. Adult *A. zoegana* were attracted to portable lights at each of the four illumination periods. There was no significant difference in the mean number of *A. zoegana* adults of either sex attracted to the fluorescent versus the ultraviolet light (i.e., 36.9 ± 15.9 [SEM] versus 46.0 ± 23.4, [$F_{(1,37)} = 0.06$; $P = 0.81$] for males, respectively, and 2.3 ± 0.8 versus 4.2 ± 1.9 [$F_{(1,37)} = 0.86$; $P = 0.36$] for females, respectively).

The mean number of male *A. zoegana* attracted to the two types of lights per night was significantly higher than females (i.e., 37.3 ± 9.7 [SEM] males versus 3.6 ± 0.7 females; $F_{(1,130)} = 16.5$, $P = 0.0001$). The highest number of males was collected during the 95 MAS illumination period, when an average of 113.9 ± 123.3 (SD) males was attracted compared to 5.5 ± 6.6 females ($t = 3.8$, df = 18, $P < 0.0001$). On July 23, 1998, there were more moths on the sheet than could be collected during the 95 MAS period at both types of lights; thus, overall male numbers at the 95 MAS period would have been even higher if the excess

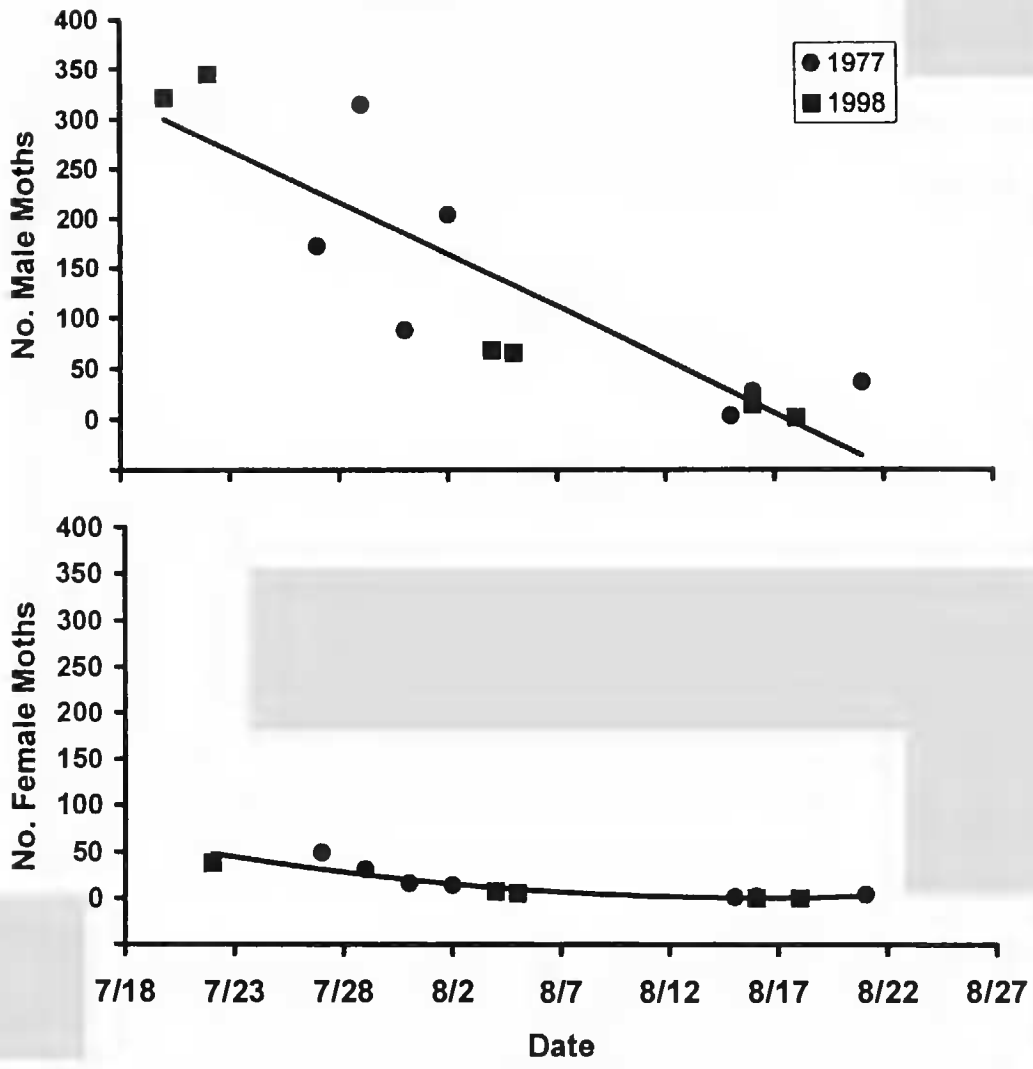

Figure 2. Mean number of *A. zoegana* adults collected at portable lights per date in 1997 and 1998.

moths had been collected. The number of males was also significantly higher than females during the 140 MAS illumination period (19.1 ± 26.7 [SD] versus 4.8 ± 8.8 [$t = 2.1$, df = 16; $P = 0.0000$), but there was no difference between male and female numbers during the 50 MAS (2.2 ± 3.0 versus 2.1 ± 2.9) and 185 MAS (3.1 ± 4.2 versus 1.9 ± 2.8) illumination periods ($P > 0.05$; Fig. 1). The male to female *A. zoegana* ratio at the four illumination periods was 51:49 at 50 MAS, 95:5 at 95 MAS, 80:20 at 140 MAS, and 62:38 at 185 MAS. Male numbers did not differ among illumination periods except for the 95 MAS which yielded significantly higher male numbers ($F_{(3,65)} = 11.9$; $P = 0.0000$). There was no significant difference in numbers of females collected among the four illumination periods ($F_{(3,65)} = 1.7$; $P = 0.17$). Total (male and female) moth numbers were not significantly different across years ($F_{(1,122)} = 0.2$; $P = 0.68$). Both male and female numbers were highest on sample dates in late July and early August, after which they gradually declined (Fig. 2).

The mean number of males and females captured in daytime hand vacuum collections was not significantly different (19.8 ± 12.2 [SD] males, 16.5 ± 7.9 females; $t = 1.4$, df = 12; $P = 0.20$). Female *A. zoegana* were collected at the rate of one per 5.5 minutes during portable light collections compared to one per 1.5 minutes during daytime collections with a hand vacuum.

Discussion

The study demonstrated that portable lights are much more attractive to *A. zoegana* males than females, especially at the 95 MAS illumination period. The

greater attraction of *A. zoegana* males to the lights was similar to behavior reported for other moth species (Sorensen & Thompson 1984, Levine 1989).

It is possible that alterations to the described technique could increase the numbers of females attracted to the light. For example, preliminary observations suggest that attraction of female moths to the portable light may increase if the females are incited to fly; this might be accomplished by a second collector walking circuitously through the knapweed within 50 m of the light while the light is illuminated. Also, it is possible that the proportion of females would have been higher if the illumination periods had been longer than 20 min. Such alterations were not examined but should be considered in future studies.

The fact that male and female numbers collected during the day were not significantly different indicates that the disproportionate number of males attracted to the portable lights was related to moth behavior rather than population sex ratio. The male-female behavioral differences were not identified, but may be related to female flight patterns. In their search for oviposition sites, females may fly at low elevations (i.e., below the top of the plant canopy), thereby minimizing their view of the portable light. Conversely, males may fly at higher elevations while searching for females, which could provide them a better view of the portable light (Tóth et al.). The daytime collection results were consistent with those of Story et al. (1991) who reported that the sex ratio of adult *A. zoegana* is 1:1 throughout most of the season. Daytime collections were not affected by the moth's flight behavior as the moth is relatively inactive during daylight hours.

As expected, numbers of both males and females attracted to the lights were highest on the late July and early August collection dates in both years, when the adult population typically peaks (Story et al. 1991). The total number of days when high numbers of *A. zoegana* adults were attracted to the light was not determined because the sampling did not necessarily start at the onset of peak emergence each summer. During this study, most moths were collected between 21 July and 3 August. It is possible that high moth numbers could also have been detected up to 7 days earlier (14 July).

Agapeta zoegana numbers collected at ultraviolet lights were generally greater than at fluorescent, but the differences were not significant due to high variability. Ultraviolet lights have been used extensively for light trapping of Lepidoptera, and studies have shown that some Lepidoptera are preferentially attracted to ultraviolet lights (Sorensen & Thompson 1984). The effectiveness of the fluorescent lights is advantageous because they are more readily available than UV lights.

High mountains, approximately 9 km west of the study site, caused sunset to occur earlier (approximately 20 minutes) for that area than reported in the World Almanac. In view of this, post-sunset moth activity in areas with flatter landscape may occur at later times following the World Almanac sunset time for that area than observed in this study.

Strong moonlight probably reduces *A. zoegana*'s attraction to lights, but insufficient data were collected to verify this hypothesis. Studies have shown that moon illuminance decreases light-trap catches of some Lepidoptera, probably because the moonlight reduces the contrast between the background and the light emitted by the portable light (Nowinszky et al. 1979, Dent & Pawar 1988, Yela & Holyoak 1997).

Because of the male *A. zoegana*'s strong attraction to light at the 95 MAS

illumination period, the use of portable lights during the 95 MAS period is an effective method for determining establishment of the moth. However, due to the low number of females attracted at all illumination periods, the use of portable lights is not a recommended technique for collecting the moth for redistribution, when conducted during the illumination periods used in this study. Preliminary studies suggest that attraction of females to light does not increase later in the night. The use of a hand vacuum during daylight hours remains a better collection method for *A. zoegana* adults (Story et al. 1999).

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